Wind Power Scheduling Considering the Impacts of Electrical Vehicles and FIT Incentive Mechanism

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Abstract. Large integration of intermittent wind generation in power system has necessitated the inclusion of more innovative and sophisticated approaches in power system operation planning. At a high penetration level, an extra fast response reserve capacity is needed to cover the shortfall of generation when a sudden variation of wind takes place. To enable a proper management of the uncertainty, this paper presents a novel framework to make the wind power a more reliable source by considering electric vehicle (EV) connection to the power grid and increase the benefits of wind power in electricity market. Electric vehicles can stabilize the output power of the wind farm by providing a kind of storage capacity for electric energy during high wind speed and deliver it in low wind speed. In addition, a Feed-In-Tariff (FIT) incentive mechanism is considered to encourage wind power owner for participating in electricity power market. This framework is implemented on a test system to illustrate the working of the proposed approach.

Keywords: Wind Energy, Electric Vehicles (EV), Investment Mechanism, Generations scheduling

1. Introduction

The increasing concerns regarding energy security, fuel price volatility, and the environmental challenges, diversifying the resources and making use of renewable energy resources has turned to be an important issue. Among the renewable energy resources, wind power generation is holding the first rank in terms of use and importance. Unlike other forms of renewable resources, the development of wind technology has resulted in wind generators which are approximately comparable to conventional units in terms of both cost and capacity ratings [1,2].

Furthermore, in order to serve the load more economic and reliable, generation companies have developed new operation strategies for their network inevitably. Traditional methods for serving the forecasted demand in power systems were based on using conventional power plant, using storages and Demand Side Management (DSM) programs as a reserve and interconnecting to adjacent network [3].

In this paper, a new concept of wind farm power management by high penetration of Electrical Vehicles EVs. are investigated which is usually referred to as “vehicle-to-grid (V2G)”. Moreover, the benefits of combining the wind power generation system with V2G concept to reduce the fluctuation of wind power and increase the wind firm benefits are discussed here. This concept makes the wind power a more reliable capacity. EV has the feature that the vehicle battery can be recharged from standard electric wall outlets while the conventional hybrid vehicles can only be charged from the internal combustion engines. V2G can be assumed as storage to provide the demand of the system during off-peak and high wind power generation period and as generation devices during peak period and low wind power generation period [4].

As shown in [5], the backbone of smart grid emphasis on environmental protection, using variable generation(such as wind, solar,…), demand response, and distributed generation such as electric vehicle technology, driving for better asset utilization, while maintaining reliable system operation, and needing for enhanced customer choice. Fig. 1 depicts these factors in relation to the new emerging smart grid paradigm, and illustrates the role of renewable energy and V2G technology in the new area.
In competitive electricity market, each firm performs its own development scheduling to obtain the most possible benefit. Moreover, the intermittency and uncertainty of wind power generations are among some of the reason that threat high cooperation of the wind power generation in competitive power market. Recently, North American Electric Reliability Corporation (NERC) published a report on the planning and the operation of power systems with large sums of wind power generation [6].

The increasing bio-environmental concerns have promoted governments to support large integrations of renewable energy in power systems by introducing obligatory Renewable Portfolio Standards (RPS) or equivalent policies [1,2]. The development of renewable energy includes a substantial economic effort in terms of support incentives, grid reinforcements, operational cost, and back up infrastructure. Until now, it’s economic and market impacts have been a less discussed topic [1]. To defeat the above mentioned problems, some mechanisms have been utilized to encourage renewable energy owner to participate in power market. The most functional mechanism used is the Feed-In-Tariff (FIT) incentive. In the authors previous works [1,2], a novel framework has been presented to study the impacts of market independent and market-based FIT on wind power investment.

The main contribution of this paper is scheduling of wind power generation along with EV technology where the impact of FIT incentive is considered for financial support of wind generation.

The rest of this paper is organized in the following order. Section 2 describes the proposed model of scheduling framework. Section 3 presents the probabilistic model of wind power. V2G technology is presented in section 4. Section 5 provides a mathematical formulation of the proposed framework. In section 6 the proposed method is implemented on a test system. Finally, the last section is devoted to conclusion.

2. Scheduling Framework

The proposed scheduling framework of wind power generation is illustrated in Fig.2 which is structured in ten blocks. The elastic demand which is considered in scheduling is illustrated in block one. The profit of the wind generation owner will be affected by fluctuation of the spot price resulting from demand elasticity.

The system regulator is also assumed to set a price cap (block 2), which determines the price in the power market. The price cap could be set to lower values in order to protect customers from remarkable price levels. The regulatory policies such as FIT incentive for wind energy and using EV along with wind power for increasing the wind generation flexibility are illustrated in blocks 3 and 4, respectively. Data required for solving the optimization problem are indicated in block 5. One of the most important impacts due to considering wind power generation is the creation of uncertainties in power production [1]. Therefore, incorporating such uncertainties in operation decisions are required which is shown in block 6. Furthermore, other uncertainties about electric vehicle which can influence on operational planning are illustrated in block 7. Since the objective of wind generation owner is to maximize his/her profit, the revenue of the owner from power market must be calculated during the operation period. This requires the calculation of electricity price at each hour of operation. The way that the electricity price is evaluated is also important. For evaluating the price of electricity, the equilibrium analysis has been applied. The scheduling of wind generation, wind firm revenue, the optimum amount of regulatory intervention such as FIT for wind are outputs of the framework (blocks 8, 9, and 10).

3. Wind Power Generation

The utilization rate of wind energy is increasing year by year because of low operation cost and developed technology. Despite these advantages, using wind energy has some disadvantages, among these demerits the most critical one is its uncertainty. This problem in power market is more severe. Therefore, certain amount of reserve for supporting wind generations should be available. For solving these problems and increasing the flexibility of network, some technical and financial methods have been suggested in recent years [1-3]. Technical methods consist using of storages like batteries, pumped storages, connecting to adjacent network, Combined Heat and Power (CHP) units, using heat storage for reserve and implementing DSM methods [3]. From financial point of view and for supporting the wind generation some methods have been suggested. The most applied mechanism used is the Feed-In-Tariff (FIT) incentive [1,2]. In this paper,
combination of two mentioned methods such as technical (electric vehicle technology) and economical support schemes (FIT incentive mechanism) is implemented for wind generation.

4. Integration of Vehicle-to-Grid (V2G)

V2G concept applies the EVs (electric vehicles) as a resource for the support of electrical grid, where power can be absorbed or sourced by the vehicle energy storage system. However, there are many intermediary steps that have to be achieved, before this vision comes to fruition [4].

The battery of a vehicle is a very small storage capacity of energy that its impact on the grid can be neglected. The typical range for commercial EV battery storage is from 1 to 60 KWh. So, in this paper, the extensive use of aggregation (in parking lots) to overcome the small storage capability/capacity of an EV is suggested. The EV parking lot is a new player whose role is to collect the EVs by attracting and retaining them with suggest incentive for owners of EVs in order to reach high storage capacity from small battery capacity of multi EVs that can affect the grid beneficially. In this paper, the availability of the EVs is not the point of interest to study and just for the convenience it is considered as uniformly distributed numbers between 0.3 and 0.9 for each hour as it will be addressed in next section [4].

5. Mathematical Modeling

A mathematical formulation of the problem is presented in this section. Here, the impacts of incentive mechanism and electrical vehicle are being considered in formulation of power generation scheduling. The optimization problem is formulated in Eq. (1) to Eq. (7). The objective function represented by Eq. (1) indicates total profits result from scheduling of power generation. Eq.(2) represents the benefits for time step t. The first and second terms in Eq. (2) represent a wind firm owner’s revenues resulting from energy sales in electricity market and support of wind power. The benefit of implementing EVs is represented by the third term, where this equation consists of the benefit resulted from sale of electricity to the network (discharging state) minus the cost caused from buying electricity from the network (charging state). The forth term illustrates the revenue or cost about trading the power by adjacent network. The operation cost and power losses cost are expressed by the fifth and sixth terms, respectively. More details about this equation (equation 2) are illustrated in Eqs. 8-11.

The sum of wind power generation, EV power generation and the power traded with adjacent network must be equal to total demand plus power losses as shown in Eq. (3). The distribution feeder constraint is illustrated by Eq. (4) which must be satisfied. Constraints (5) and (6) are the bounds upon the decision variables which indicate the power boundary for the wind generation and energy storage capacity of the EVs' battery. Finally, Eq. (7) represents the price cap constraint to prevent increasing the price of electricity.

$$\Psi_{0} = \text{Max} \left\{ \sum_{bh} B_{t}(P_{gw,t}, D_{t}, P_{ev,t}, \pi_{t}) \right\}$$ (1)

$$B_{t} = B_{\text{energy},t} + B_{\text{FIT},t} + B_{\text{EV},t} + B_{\text{trade},t} - C_{\text{var},t} - C_{\text{loss},t}$$ (2)
In competitive power market, if the wind power generation’s revenue is similar to other generators, the risk of revenues would be high, especially in low wind period. As a result, the rate of renewable energy may be reduced, which is not acceptable for power market policy makers. In this paper, the impacts of FIT mechanism on wind power scheduling are being investigated. Eq. (12) represents this revenue of wind firms.

\[
P_{\text{trade}} + \sum_{b=1}^{\text{nlb}} P_{\text{GW,b,t}} + \sum_{V=1}^{V} P_{\text{EV,V,t}} = D_{t} + \sum_{ij} P_{\text{loss,ij,t}}
\]

\[
P_{ij} \leq P_{ij}^{\text{Max}}
\]

\[
P_{\text{GW,Min}} \leq P_{\text{GW,t}} \leq P_{\text{GW,Max}}
\]

\[
P_{\text{EV,Min}} \leq P_{\text{EV,t}} \leq P_{\text{EV,Max}}
\]

\[
\pi_{t} \leq PC
\]

\[
B_{\text{energy,}t} = \sum_{b=1}^{\text{nlb}} [P_{\text{GW,b,t}} \cdot \pi_{t}] + \sum_{V=1}^{V} [P_{\text{EV,V,t}} \cdot \pi_{t}]
\]

\[
B_{\text{trade,}t} = P_{\text{trade,}t} \cdot \pi_{\text{trade,}t}
\]

\[
C_{\text{var,}t} = \sum_{b=1}^{\text{nlb}} C_{\text{var,MWh}} \cdot P_{\text{GW,t}}
\]

\[
C_{\text{loss,}t} = \sum_{ij} \pi_{MCP,t} \cdot P_{\text{loss,ij,t}}
\]

6. Numerical Studies

The Swift Current wind data are used for numerical studies in this paper [1]. A case study system consisting of wind farm, EVs parking lot in order to smooth out the intermittent power of the wind farm and adjacent network as shown in Fig. 3. The output of wind power generations in 24 hours are illustrated in Figs. 6-8(dashed line). The peak load of the distribution system is 42.59 MW. The Power purchased through the existing substation and the power generated from the new wind and EV sources should meet the forecast peak demand and satisfy the system losses. Data about test system are from [4,7]. The results of wind generation scheduling are illustrated in the following. Two case studies are considered in the study as below:

Case study1: In this study, there is no electric vehicle, but the impact of FIT as a regulatory intervention has been considered for wind generation. The amount of incentive for wind power generation in three buses is illustrated in Fig. 4. The results show that the amount of incentive is high when the wind production is low and vice versa. This result is proper for the competitive nature of power market.

Case study2: In this case, the impact of electricity generation by EVs. are considered to increase the flexibility of wind. In this study, the amount of FIT incentive mechanisms is differs to case 1, because the EV help wind firms to have a fixed output in each year and the ratio of FIT incentive is devoted to encourage EV drivers to cooperate in electricity market.

The results of this case study are shown in Figs. 5–7. These figures show the different storage time, and the output power of wind generator with and without integration of EVs. As it is shown in these figures, connection of EVs can smooth the output power of wind farm. The significant characteristic of using this method is its flexibility in using different numbers of EVs for providing an optimum amount of storage capacity. From the behaviour of the system, the equivalent storage capacities are 1070, 830, 1300 KWh. Therefore, the number of required EVs is 35, 28, and 43 vehicles, respectively. The optimum amount of FIT incentive for wind firms in compare to case study 1 are illustrated in Figs. 8-10, respectively.

7. Conclusion

This paper presents a novel framework to make the wind power a more flexible source by using electric vehicle (EV) technology. Furthermore, the impact of incentive mechanism is considered for wind energy. Two case studies are investigated, one without EV and the other with EV. The result show that the amount of
incentive for wind power decreased in case of using EV. This happens because some ratio of this incentive will be devoted to the promotion paid to EVs drivers. This procedure will decrease the uncertainty of EVs. Drivers and encourage them to participate in electricity market. Therefore EV could smooth the output of wind generation in intervals of one hour, and this will result in flexibility of wind generation to participate in electricity market. A more precise modelling of EV can be proposed for the future work of this study.

![Fig. 3. Test system with wind farm & EV](image)

![Fig. 4. Obtained FIT for three wind farms](image)

![Fig. 5. EV implementation in bus 1](image)

![Fig. 6. EV implementation in bus 2](image)

![Fig. 7. EV implementation in bus 3](image)

![Fig. 8. Comparison of FIT (case 1 and 2) in bus 1](image)

![Fig. 9. Comparison of FIT (case 1 and 2) in bus 2](image)

![Fig. 10. Comparison of FIT (case 1 and 2) in bus 3](image)

8. References


